Numerical Modeling of Acoustic Propagation In a Variable Shallow Water Waveguide

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LONG-TERM GOALS

Random variability in shallow water will induce variability in a propagating acoustic field. The long-term goal of this research is to quantify how random variability in the ocean environment translates into random variability in the acoustic field and the associated signal processing algorithms propagation in the mid-frequency (1-10 kHz) band. In the present funding cycle, the emphasis is on the effects of the internal tide and linear internal waves.

OBJECTIVES

The first objective for the current funding cycle is to quantify how the slowing rising thermocline caused by the internal tide affects the mean acoustic intensity. Having successfully modeled the mean intensity, the primary objective is to then understand how the fluctuations in intensity about the mean are caused by linear internal waves.

APPROACH

Our approach is a mixture of data analysis and modeling. We use acoustic and environmental data collected during the Shallow Water 2006 Experiment (SW06).[1] These experimental observations guide the development of models. This work is done in close collaboration with other SW06 participants especially Dajun Tang, Jie Yang, and Frank Henyey.

Figure 1 shows the positioning of the SW06 assets on 18 August 2006. The acoustic source was deployed off the stern of the *R/V Knorr* at depth 40 m. Of present interest are 20 ms duration linear frequency-modulated (LFM) chirp signals in the 1.5 to 10 kHz band that were transmitted every 19 s. The signals were recorded on MORAY moored receiving system that had two short vertical sub arrays with the bottom four elements, one at depth 25 m and the other at 50 m. Two acoustic data sets were collected, each

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14. ABSTRACT
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approximately 7 hours in duration, one with the *R/V Knorr* at fixed position 550 m away from MORAY, and the second with the *R/V Knorr* slowly transiting while towing the source. During the tow, the range to MORAY increased from 100 m to 8 km. Concurrent oceanographic data were collected on five moorings (labeled 14-17 and 54 in the figure). In addition, investigators onboard the *R/V Oceanus* collected oceanographic data 250 m east of the *R/V Knorr* as a non-linear internal wave first approached and then passed the two ships. The wave subsequently passed MORAY and the oceanographic moorings. X-band radar measurements estimated the bearing and speed of the wave. Note that the bearing of the internal wave nearly coincided with the bearing from the *R/V Knorr* to MORAY.

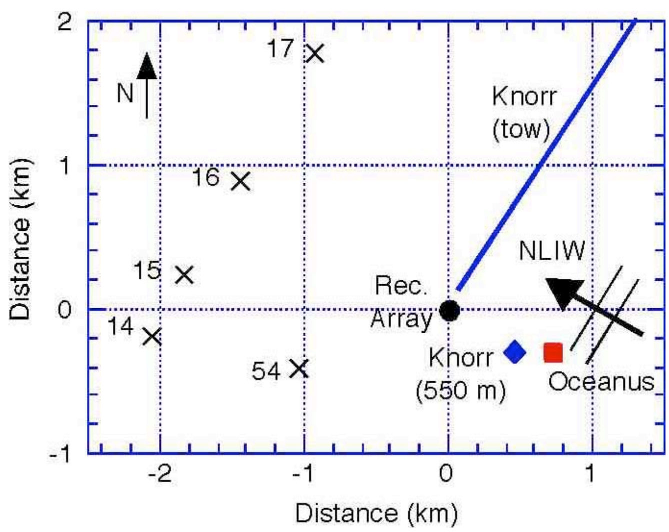

Figure 1. *Experiment geometry. Acoustic source deployed off the stern of the R/V Knorr. Two acoustic data sets: fixed range 550 m and slow tow. Oceanographic data collected on R/V Oceanus and moorings labeled 14-17 and 54.*

WORK COMPLETED

An analysis of the SW06 550 m path data taken while a non-linear internal wave passed was completed. In the current fiscal year, a previously submitted paper documenting this work was published.[2] The paper shows how non-linear internal waves can cause new acoustic paths to be generated. This year, a journal paper was written and accepted for publication that documents how the slowing rising thermocline caused by the internal tide affects the mean acoustic intensity for both the 550 m and towed-source data sets.[3] A previously submitted journal paper looking at intensity fluctuations was accepted for publication in this fiscal year.[4] New results showing intensity fluctuations in the SW06 towed-source data were presented in an invited talk at the Acoustical Society of America meeting in Portland.[5]

RESULTS

The internal tide causes both the generation of nonlinear internal waves and the subsequent slow rising of the high-gradient part of the thermocline. The latter has been studied in the current fiscal year both for the fixed range 550 m and towed-source SW06 data. For the fixed-range data, a 5 dB change in intensity was observed in the data and correctly modeled. For the towed-source data, among other effects, a 2 dB dip in transmission loss between ranges 5 and 7 km was observed in the data and correctly modeled using oceanographic mooring data as input. Water-column effects of this level may be significant as they could cause erroneous results if one is trying to predict the mean level of ensonification in an active sonar scenario. For the cases considered, however, the mean water column effects were predictable when data from nearby oceanographic moorings were incorporated into the numerical simulations.

While a deterministic acoustic model using nearby oceanographic mooring data as input is adequate for predicting the mean intensity, it fails to predict fluctuations in intensity. Figure 2 shows a model-data comparison for intensity in the 3 to 3.3 kHz band and range near 3 km. Both the model and data images have 20 dB dynamic range. The range-independent model result in the left panel shows a regular pattern of intensity striations, bands of high intensity. The striations are consistent with a value for the waveguide invariant[6] β approximately equal to 2. The right panel shows SW06 towed-source results. The 300 m horizontal aperture (range) was synthesized by towing the acoustic source and took 20 minutes to generate. The experimental results are much more granular than the simulation; while striations are still evident, they are less distinct. The simulation, which ignores the temporal and spatial variability introduced by internal waves, over predicts the stability of the pattern. Ongoing research is attempting to quantify the "beta content" of the experimental results.

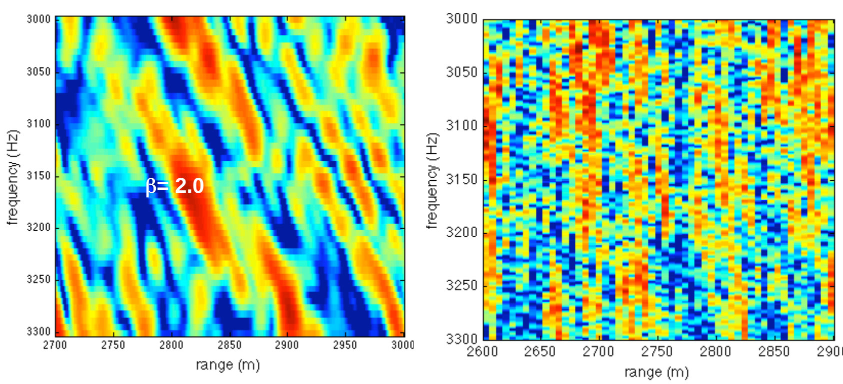

Figure 2*. Intensity striation patterns in at mid-frequencies for SW06. Left: range-independent PE simulation. Right: Experimental results generated by synthesizing horizontal array. Plots have similar sampling in frequency (~1 Hz) and range (~6 m) and same 20 dB dynamic range.*

IMPACT/APPLICATIONS

Internal waves are a ubiquitous feature of shallow water oceanography. Even when event-like non-linear internal waves are absent, random background internal waves will affect acoustic propagation in the mid-frequency regime relevant to Navy sonar systems. By studying data sets such as collected during the SW06 experiment, these effects can be quantified as a first step towards developing a predictive capability and possible mitigation strategies.

RELATED PROJECTS

Numerous ONR-supported investigators were involved in the SW06 Experiment and are analyzing the collected data.

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HONORS/AWARDS/PRIZES

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